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GRANT NO. AFOSR 77-3365

Project Task No. 2301/A1

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ANNUAL REPORT NO. 1 ON

STUDIES OF TRANSIENT DISCHARGES

P. F. WILLIAMS and M. A. GUNDERSEN

Grant No. AFOSR 77-3365

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Work during the grant period from June 15, 1977 through June 14, 1978 may be divided into three areas: (1) development of an optical multi-channel spectroscopic facility as described in our original proposal, (2) the design and construction of a vacuum/pressure cell suitable for use in laser-induced breakdown experiments, and (3) preliminary experimental efforts. At the end of the grant period, the multichannel spectroscopic facility was fully operational, with only minor additions and improvements still remaining to be implemented; the vacuum/pressure cell had been completed and put into use; and preliminary experimental results had been obtained using this cell and using some earlier, simpler gaps.

I. <u>Development of the Optical Multi-channel Spectroscopic Facility</u>.

Immediately after being officially notified of the award of the grant a serious market survey of the commercially available optical multichannel analyzer systems was undertaken. On the basis of this survey it was concluded the computer-controlled "OMA 2" system with cooled SIT detector marketed by Princeton Applied Research Corporation represented the best solution for our application. Advantages of the system include:

1) Excellent Sensitivity. The unit is capable of near-single-photon detectivity while offering in cooled operation very low dark count.

2) High Temporal Resolution. The 40 nsec. resolution quoted for the system was the best available. Since this figure represents the rise and fall times of the high voltage

gate generator and not the ultimate speed of the image intensifier, higher resolution should be attainable in applications where the tube need only be turned off after a set period.

3) Two-Dimensional Scan. The system has a fully-implemented two-dimensional scan capability, allowing it to be used for ultra-high sensitivity optical photography, and, perhaps, spatially resolved spectroscopy.

4) Computer Control. All aspects of the system are under computer control, allowing exceptional versatility.

5) Cost. When used in conjunction with the Tektronix 4051 minicomputer which was already present in the laboratory, this system was the lowest priced of those available.

The principal drawback of the system centered around the requirement for a suitable interface between it and the Tektronix 4051 minicomputer. Since the system was designed to be controlled by a different minicomputer with very different characteristics, the design and construction of the interface represented a significant engineering problem, and considerable time was spent in this regard. The interface is now operational and is working satisfactorily. Software for the minicomputer has also been written to allow convenient control of the OMA and it is expected that improvements in the system program will be made on a continuing basis as more experience is gained with the system. Additionally, the memory of the Tektronix minicomputer has been expanded to the system maximum of 32 K bytes.

The primary problem which the interface must deal with is related to the relative slowness of the 4051. The OMA outputs data at a rate of up to 20 us. per 16-bit word. A cumulative sum of data in up to 512 channels must be kept, and the 4051 is much too slow to accomplish the task at the required rate. Additionally the 4051 data bus is 8-bit parallel whereas the OMA data bus is 16-bit, so that 8-16 and 16-8 bit converters are required for the 4051 and the OMA to communicate.

The accumulation of data from the OMA is accomplished through the use of 1K of 16-bit static RAM memory. TTL binary adders are used to sum incoming data with the corresponding data in memory. Memory address is specified by use of a 12 bit binary counter which is reset at the start of each frame and incremented with every new channel. A string of one shot multivibrators provides pulses in the correct sequential timing to activate the operations required for each cycle. The interface operates with a 16 bit parallel data bus. Communication with the 8-bit General Purpose Interface Bus of the 4051 is accomplished through the use of 8-16 and 16-8 bit converters and H.P. 3-wire handshake interface circuitry. For readout of the contents of memory to the 4051, the address counter is reset and then sequentially incremented using the data-accepted pulse from the 4051. The interface is completely computer controlled, with instructions being decoded by a 4 - 16 wire demultiplexer tied to the topmost 4-bits of the 16-bit bus. With this arrangement, the four most significant bits on the data bus constitute the instruction to the interface (such as clear memory or set address counter) and the other 12 bits may be used for the transmission of data (such as the address to be placed in the address counter).

Optical interfacing of the SIT vidicon detector to a spectrograph was also required. Such an interface has been constructed which couples the OMA to a 0.5 m. Jarrell-Ash monochromator already present in the laboratory. With a 1200 g/mm grating, this unit provides a dispersion in the visible of 16 A/mm, giving a spectral resolution (considering the spatial resolution of the detector) of about 0.8 A, and a spectral range of about 200 A for one spectrum. This resolution was obtained for slit heights less than approximately 4mm, but for larger slit heights the resolution was degraded at both ends of the spectral range as a result of pin cushion distortion in the electron optics of the image intensifier.

In order to obtain time-resolved data, a PAR Model 1211 high voltage pulse generator was purchased to gate the intensified detector of the OMA. This unit was installed and tested. We found that when the pulse height was properly adjusted gate times of 100 ns. and longer could be used with no noticeable degradation in the spatial resolution of the detector, and that a gate time of down to 50 ns. could be used with only slight degradation of spatial resolution. There did appear to be some degradation of detector efficiency in the gated mode which we do not understand.

II. Vacuum/Pressure Cell for Laser-Induced Breakdown Studies.

For studies into the basic physical processes occurring during laser-induced breakdown it is necessary to be able to control both the pressure and the constitution of the gas in which the breakdown occurs. For this reason a cell to enclose the gap was designed and constructed. The cell is capable of operation at moderately high vacuum (the use of O-ring seals limits the ultimate pressure to 10^{-6} Torr), and at positive pressures up to a few atmospheres. One electrode of the gap has a small hole drilled through the center of it so that a laser beam may be introduced in a longitudinal geometry. The gap separation may be adjusted by changing spacers, and both electrodes are electrically isolated from the metallic cell for maximum flexibility. Transverse to the gap axis is a viewing port with roughly f/2 aperture for optically analyzing the discharge. All windows are of CaF_2 to allow the greatest spectral range.

Two circuits were used to apply voltage to the gap. In the first a capacitor was placed in shunt across the gap and charged through a large resistor connected to a regulated power supply. This circuit performed adequately, but the voltage it supplied decayed exponentially after the arc initiation, making the interpretation of data obtained during the arc difficult. In the second circuit a length of RG-8 cable charged through a large resistor was used to supply voltage and current. This circuit simplifies the interpretation of data in that it behaves like a constant voltage source with 50Ω output impedance for a length of time equal to a cable roundtrip time at the signal propagation velocity. Additionally, by carefully matching the impedance of the load to that of the cable, the current pulse may be made to shut off cleanly, facilitating the interpretation of data obtained after the arc in terms of the decay of electron density. An oscillogram of a current pulse obtained by monitoring the voltage across the 50Ω load resistor is shown in Fig.1. A schematic dia-

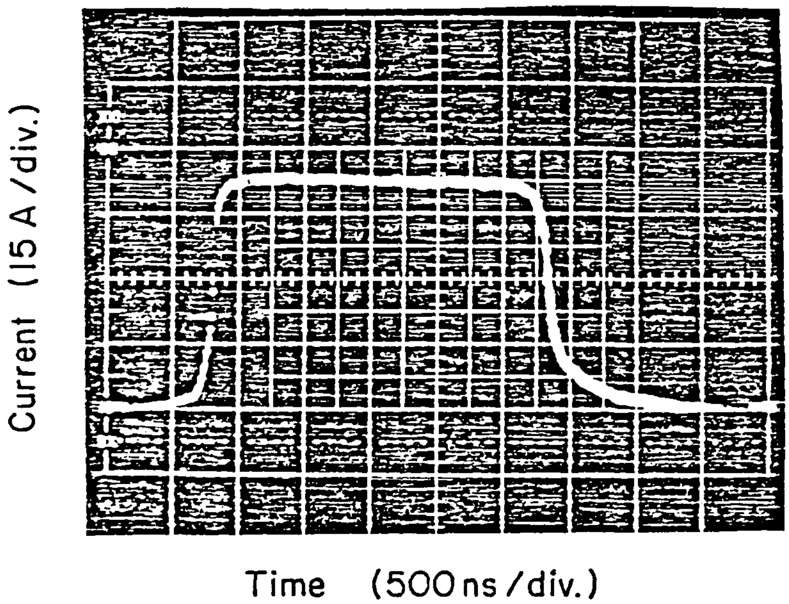

Fig. 1. Current pulse in laser-triggered gap.
H_2 at 350 Torr, 5 kV, 50 Ω load.

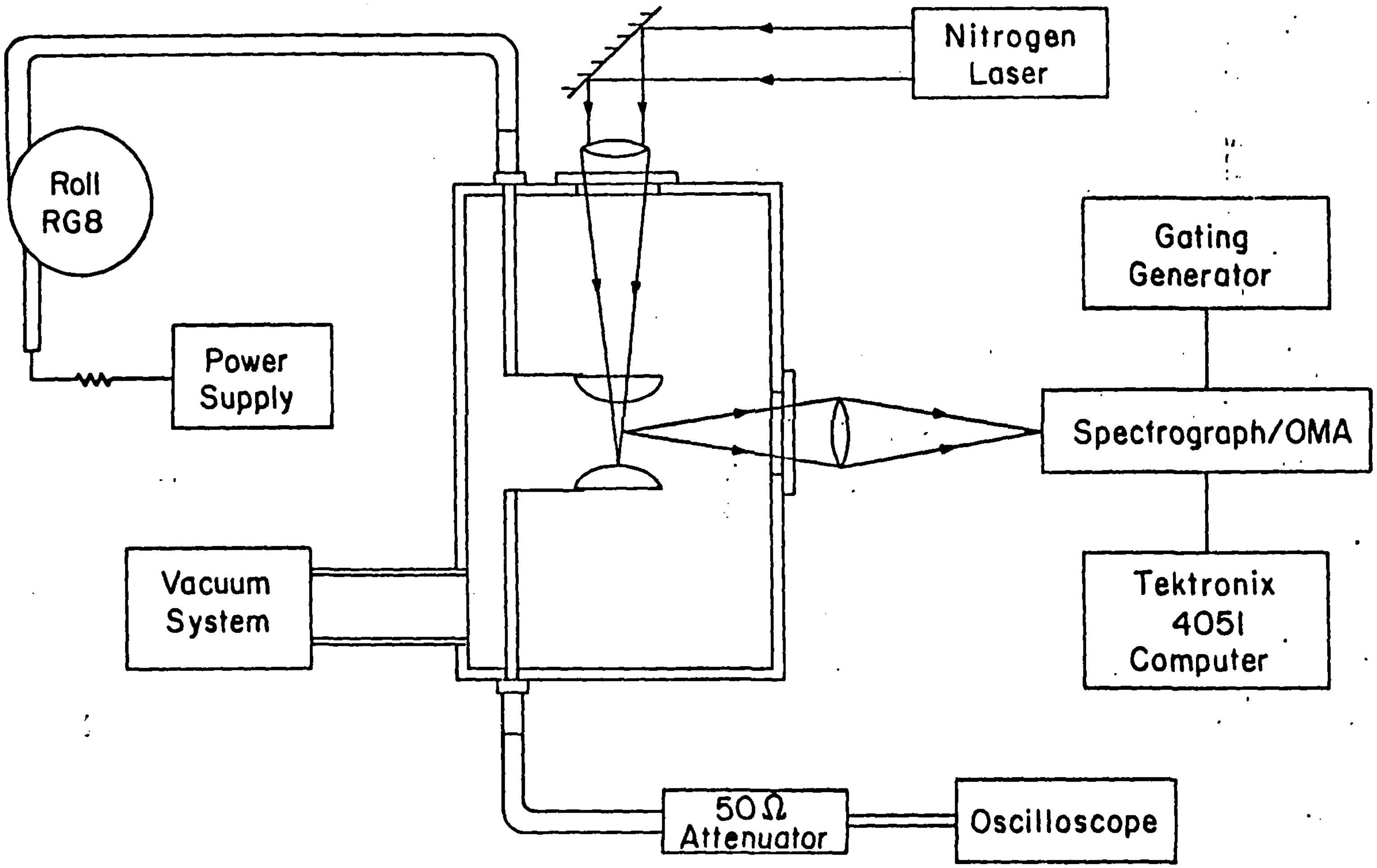

Fig. 2 Schematic drawing of experimental setup.

gram of the entire experimental set-up is shown in Fig.2.

In use the cell performed adequately but three problems with it have been noted. First, with the pumping station we are using, the ultimate vacuum which we have achieved in the cell is 10^{-4} Torr. High vacuum techniques were not used in the construction of the cell, and either outgassing of some of the nylon insulators or a number of small leaks — real or virtual — contribute to a leak rate of about 1 - 2 mTorr per minute when the evacuated cell is valved off from the pump station. Secondly, for some ranges of pressure and applied voltage discharges occur to the cell wall rather than across the gap. The problem was solved by placing suitable insulating material around the electrical feed lines, but polarization changes on the dielectric surface may distort rapidly varying voltage waveforms. Finally, to facilitate optical access, electrical feed-throughs were placed in a non-coaxial geometry. As a result, the impedance of the transmission line in the region of the cell is not well matched to the RG-8 cable, and multiple reflection may occur within it, distorting the voltage waveform.

III. Preliminary Experimental Results.

Before the OMA and vacuum/pressure cell were available a number of exploratory, preliminary experiments were conducted in order to obtain a feeling for the behavior of spark gaps induced to breakdown either by over-voltage or by laser triggering. Gap current and voltage as a function of time were measured, both for gaps which were over-volted with a pulse generator, and for under-volted gaps which were induced to breakdown with a laser. In these laser-induced breakdown experiments, the laser was not introduced in a longitudinal geometry, but rather entered the gap in a direction nearly transverse to it. Additionally, spectral measurements of the emission from these gaps were obtained on a single channel basis using a 0.5 m. monochromator and a photomultiplier. Time resolution was provided mainly by looking at the photomultiplier output current on an oscilloscope.

In these first experiments, the gap was open to the air so that experiments in which the pressure or constitution of the gas in the gap was varied were not possible. For the over-volted gap, one electrode was a flat steel plate and the other a very dull steel point. The point-plane geometry was used to spatially localize the arc in order to facilitate spectral measurements. For laser-induced breakdown, the gap consisted of two brass electrodes with roughly a constant-field profile.

In the studies of the over-volted gap the emission could be separated into two components, a spectrally continuous component extending from the visible to wavelengths below 2000 A, and a component consisting of a large number of sharp, discrete spectral lines. Many of these lines could be associated with the electrode material. The continuum component had the property that it occurred only at the time of the initial breakdown of the gap, whereas, the discrete component was observed throughout the current pulse. Curiously, in the preliminary work of laser-induced breakdown this continuum emission was not seen.

In the studies of laser-induced breakdown, it was found that using the N_2 laser ($\sim$500 Kw) with nearly transverse introduction of the beam into the gap it was possible to cause breakdown for gap voltages significantly below the static breakdown voltage by focussing on one electrode. When the laser was tightly focussed on an electrode a small fireball was produced, accompanied by an audible "snap". The fireball and the "snap" disappeared when the laser was defocussed, and it was found that under these conditions the gap did not breakdown, indicating that the fireball is required for breakdown to occur. Except for the absence of the continuum emission component at the time of gap breakdown, the spectra observed in the laser-triggered experiments were qualitatively similar to those observed in the over-volted gaps.

When the vacuum/pressure cell became available measurements of gap current and emission spectra of laser-triggered discharges in hydrogen were made. Although the data obtained with the new cell were qualitatively similar to data obtained earlier on the open-air gap, a number of differences were found. The experimental conditions were, however, significantly different in the two groups of experiemnts, and it is difficult to assess the role of a given parameter on the discharge characteristics without much more extensive investigations.

The following observations were made during the grant period.

1. After the initiation of the arc in hydrogen a number of strong lines were observed, among which were the $H\alpha$, $H\beta$, and $H\gamma$ lines of atomic hydrogen. Since these lines were strongly stark broadened, time and space-resolved electron density measurements during the arc appeared possible.[1] Work since that time has born this expectation out.

2. The time delay between the arrival of the triggering laser pulse and the closure of the gap by the arc was measured under a variety of conditions in hydrogen. Depending on gap voltage and pressure, delays ranging from less than 100 ns. to several microseconds were observed. For the longer delays, considerable temporal jitter (in the microsecond range) in the delay was present.

3. During the time between the arrival of the triggering laser pulse and the gap closure, very little optical emission is observed, at least for discharges in hydrogen.[2]

4. The minimum delay time occurred when the triggering laser was tightly focussed on the electrode. Focussing in front of the electrode (in the middle of the gap) and focussing the same distance behind the electrode resulted in similar delays - indicating that in this pressure range (300 Torr) the small fireball and not a preconditioning phenomenon is mainly responsible for the initiation of breakdown.

5. Some evidence of the preconditioning effect reported by Guenther and Bettis[3,4] was observed in that the arc seemed to follow the path of the triggering laser, but the results were not conclusive. It should be noted in this regard that the gap conditions in these experiments were significantly different than those of Guenther and Bettis, so that the presence of the effect in one experiment does not require it in the other.

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Progress ~~during the time period June 15, 1977 through June 14, 1978~~ in our program to study the basic physical processes responsible for laser-induced breakdown of spark gaps is reported. The major accomplishments during this period include the implementation of a gated computer-controlled, optical multichannel analyzer spectroscopy system, the design and construction of a suitable vacuum/pressure cell housing for the spark gap along with necessary support equipment, and the acquisition of preliminary experimental results on laser induced breakdown.